Second TPF/Darwin International Conference
San Diego, California July 26-29, 2004

Image Reconstruction and Source Extraction for TPF-I: A Gaussian Plus Positivity Algorithm

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ABSTRACT

We have developed an algorithm based on Richardson & Marsh (1983) to reconstruct the image from the sine/cosine chopped outputs of a dual nulling interferometer. For planet signal extraction, by incorporating the additional piece of prior knowledge that the true image is dominated by point sources, one can employ the same basic methodology to estimate the most probable set of point sources in a way that combines the measurements at all wavelengths simultaneously. The algorithm is also applicable for general astrophysical imaging with TPF-I.

Subject headings: techniques: image processing — stars: imaging — stars: planetary systems

1. Introduction

The algorithm treats the ensemble of possible images as a Gaussian random process subject to a positivity constraint, and contains no limitations on the presence of negative lobes in the PSF. It overcomes the limitations of the Maximum Correlation Method.

Measurement model: $y = Ax + n$, where

- y is a vector whose components are the time series (sine and cosine chop)
- x is a vector whose components represent the pixel values of the true image (also includes a constant leakage term)
- A is a matrix which contains the PSF values at each time
- n is the measurement noise.

The methodology is basically a Bayesian procedure: Maximize the probability density of the image, conditioned on the data (i.e., maximize $P(x|y)$ with respect to x. $P(x|y)$ is a multi-mountain function which makes it difficult to find the global maximum. We solve this problem by re-expressing it as the minimization of a convex function $f(w)$, where w is a conjugate vector with the same dimensionality as the measurement vector.

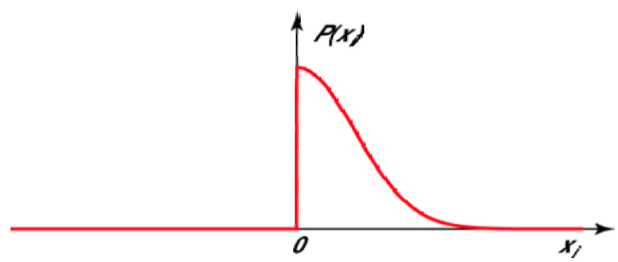

Fig. 1 Prior Statistics. $P(x_i)$ is the a priori probability density of the ith pixel value in the true image, n is the zero-mean Gaussian random process (GRP), and x is the GRP with a positivity constraint.

2. Imaging Steps

1. Initial Image: Input time data (sine or sine-and-cosine chops with corresponding PSFs).

2. FIT planet parameters: Examine the image and identify the number of planets (N). Input the number of planets and fit planet parameters from the Time-Data using a maximum likelihood algorithm.

3. Clean: Subtract fitted planets (N) from the Time-Data.

4. Residual Image: Image as in Step 1, but using the planet subtracted Time-Data as input. Examine the residual image and identify the number of new planets (M).

5. Improve Clean: Input number of planets ($N + M$) and fit planet parameters from the original Time-Data using a Maximum likelihood algorithm. Subtract fitted planets ($N + M$) from the original Time-Data.

6. Repeat Steps 4 and 5 until no new planet is seen in the residual image.

7. Add ALL planets back into the final residual image.

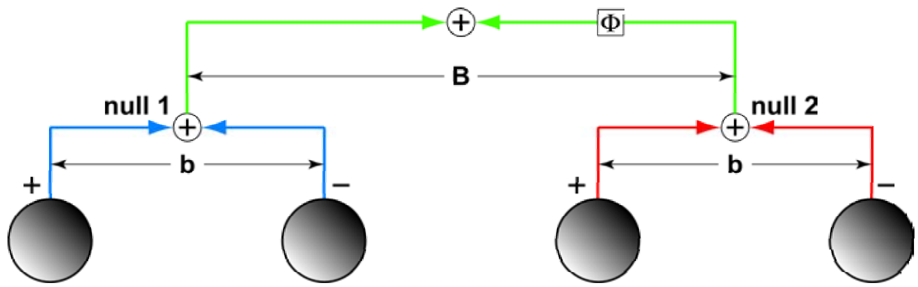

Fig. 2 Schematic of a Double Bracewell and phase chop. In the case of a Free-flyer X-config, with the baseline **b** is at 90 to **B**.

3. Data Simulation

Signal and Noise model as given by Beichman & Velusamy (1999) for $1Z$ inclination, 30, and 3 planets (at 1–2 AU), with fluxes: 9:4:1 (E) around a G2V star at 10 pc. A total 24 hr integration was used for both sine and cosine chops. Assumed are a telescope diameter of 3.2 m and a null depth of 10^{-6}.

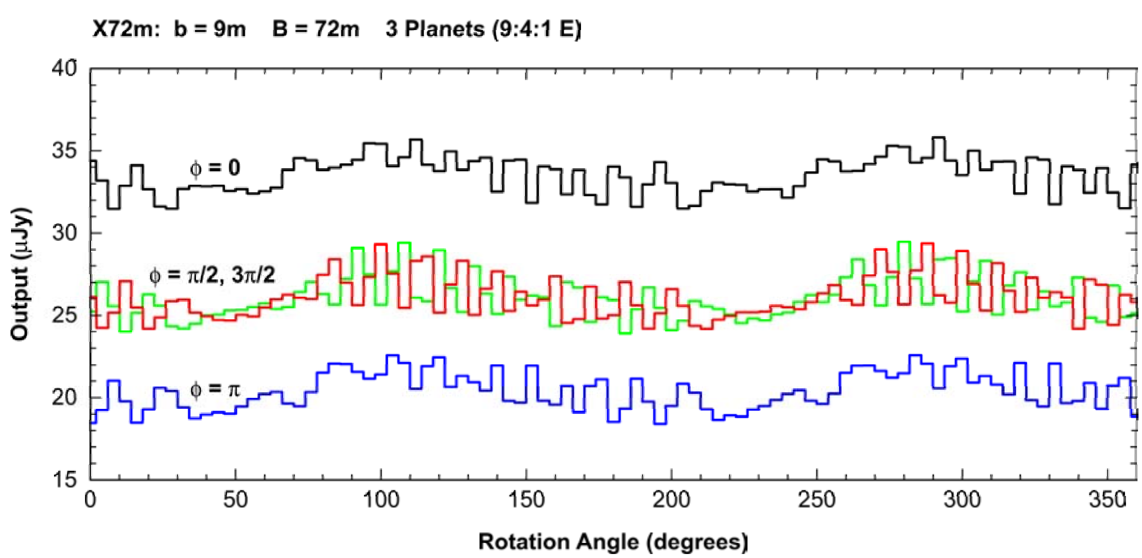

Fig. 3 Example of time-data output at 12 μm of TPF-I (Free Flyer X-config) for three planets with 9, 4, and 1 times Earth flux.

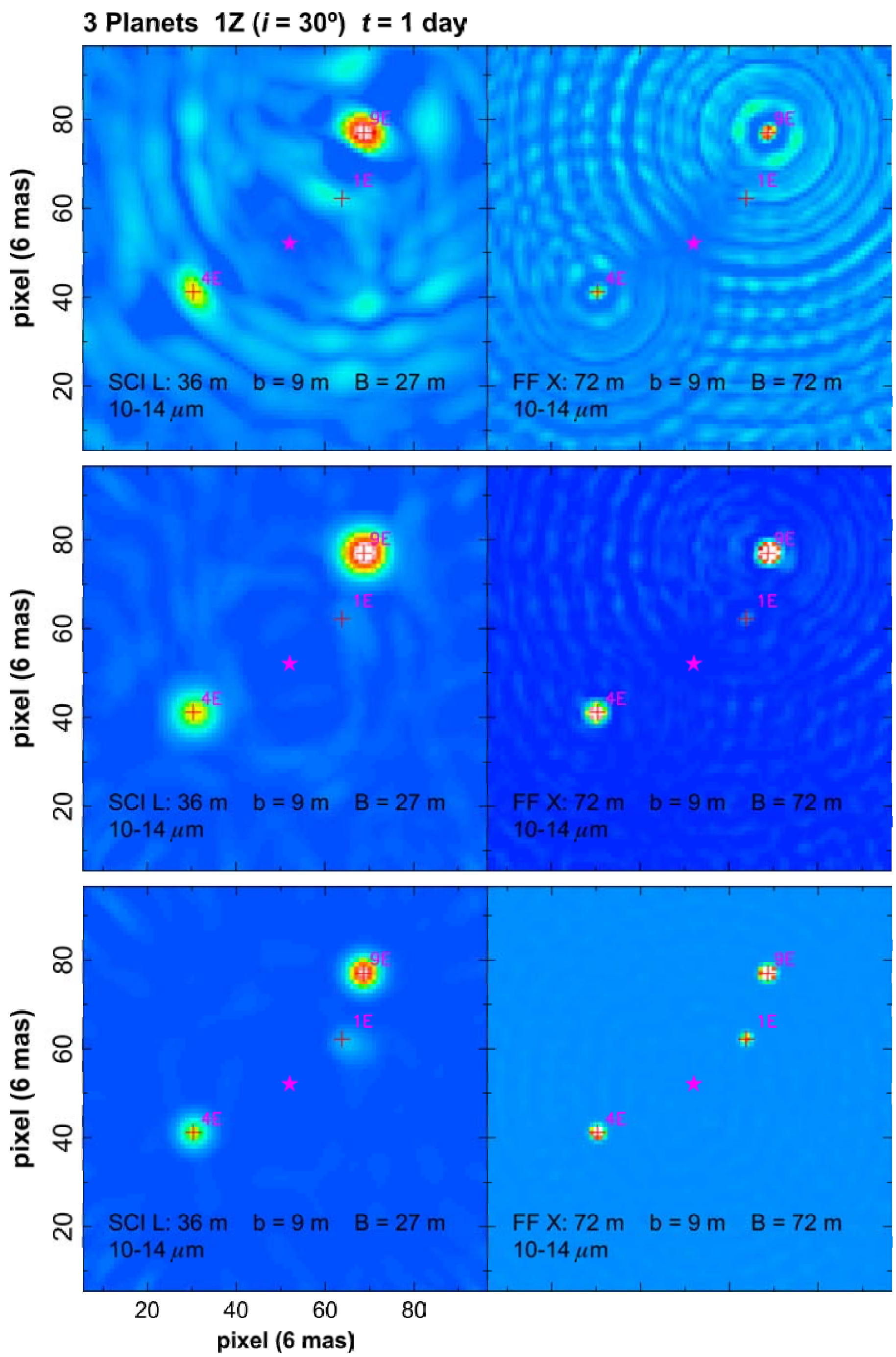

Fig. 4 Image reconstruction using both sine and cosine chop for 3 planets (fluxes 9:4:1 Earth) for SCI (left) and Free Flyer (right). The (upper) reconstructed image from the time-data (as in Fig. 2) - after Step 1. (middle) Preliminary clean using the 2 brightest components - after Step 3. (lower) Improved clean using the maximum likelihood source extraction for 3 planets simultaneously - Step 7.

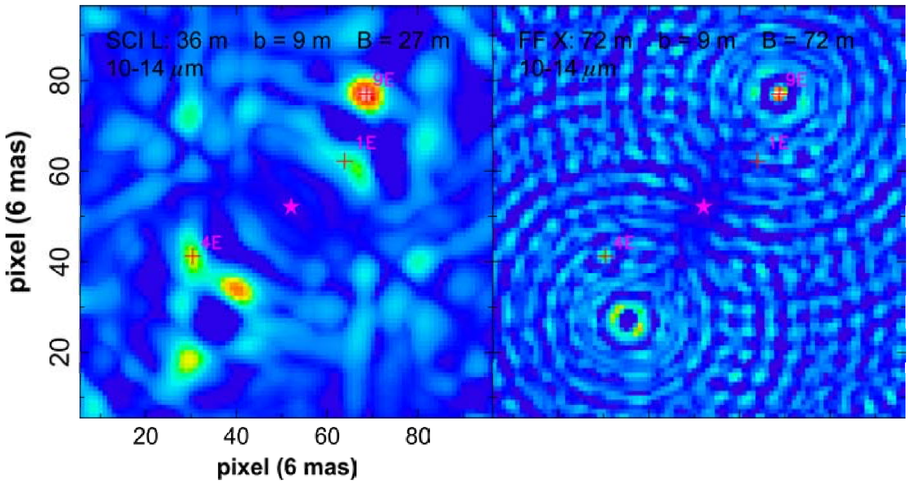

Fig. 5 Image reconstruction using only the sine chop data. Note the ghost responses seen at symmetrically opposite positions. Including the cosine chop alleviates the ghost responses and puts all the flux in the correct location of the planet (compare with upper panel in Fig. 4).

4. Astrophysical Images

This assumes only a small modification to TPF-I. Uses SUM beam from Bracewell Nulling combiner instead of the null beam phase chops 0, p/2, p, 3p/2 in dual beam combiner as for planet detection. Gaussian Positivity reconstruction algorithm using the all four phase chop time series.

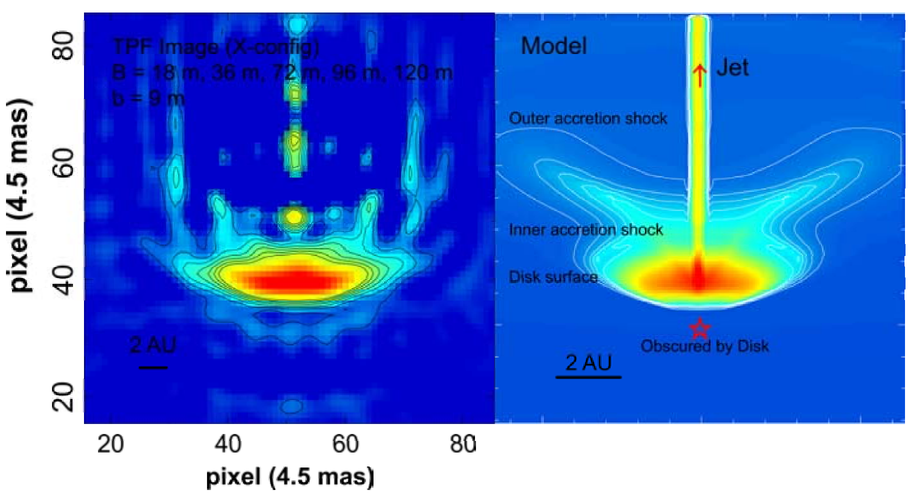

Fig. 6 The image shown combines several baselines for the Free Flyer X-config. H_2 17 μm disk-jet image (inclination 70) from York & Bodenheimer (1999).

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